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SELECTION AND APPLICATION OF LIQUID AND SEMI-SOLID LUBRICANTS IN AEROSPACE VEHICLES AND SUPPORTING EQUIPMENT

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ELEMENTS WHICH INFLUENCE LUBRICANT APPLICABILITY AND EFFECTIVENESS UPON WHICH SELECTION OF THE PROPER LUBRICANT IS DEPENDENT ARE REVIEWED. THESE ELEMENTS INCLUDE: ADVANTAGES AND DISADVANTAGES OF LIQUID AND SEMI-SOLID LUBRICANTS, TYPES OF AVAILABLE LUBRICANTS, DESIGN PARAMETERS, TYPE OF UNIT TO BE LUBRICATED, MECHANICAL AND ENVIRONMENTAL CONDITIONS, METHODS OF LUBRICANT APPLICATION AND TYPES OF LUBRICANT DEVICES AVAILABLE AND THEIR MODE OF INSTALLATION. TYPICAL LUBRICANT PROBLEMS AND THEIR SOLUTIONS ARE ALSO INCLUDED.

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FOREWORD

This report was prepared by the Fluid & Lubricant Materials Branch, Nonmetallic Materials Division, Air Force Materials Laboratory, Research and Technology Division. The preparation of the report was initiated under Project No. 7343 "Aerospace Lubricants". This report was prepared by Dr. R. L. Adamczak, Mr. R. J. Benzing, and Mr. H. Schwenker.

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ABSTRACT

Currently available liquid and semi-solid lubricants and their general applications are given. Elements which influence lubricant applicability and effectiveness upon which selection of the proper lubricant is dependent are reviewed. These elements include; the advantages and disadvantages of liquid and semi-solid lubricants, types of available lubricants, design parameters, type of unit to be lubricated, mechanical and environmental conditions, methods of lubricant application and types of lubricant devices available and their mode of installation. Typical lubricant problems and their solutions are also included.

INTRODUCTION

The liquids and greases discussed in this paper are those materials customarily used to lubricate aerospace vehicles and/or their supporting equipment. Their job is primarily to act as a medium for reducing friction and wear between moving parts, however, they may also be called up to act as heat transfer mediums, anti-rust and corrosion agents, sealants, scavengers for contaminants and degradation products, and as power transmission fluids. They are composed of a mixture of components, the major portions being a thickener and a fluid or a fluid or a blend of fluids and the minor portions consisting of various additives. The use of additives has always been necessary, because of the inherent weakness of base fluids. With the demands of aerospace equipment and the environments in which they must operate today, liquid and grease lubricants need additives now - more than ever before. Additives used include such materials as oxidation and/or corrosion inhibitors, anti-wear agents, dispersants, viscosity index improvers, foam preventives, rust inhibitors and heavy load carrying agents.

Selection of the proper lubricant is dependent upon a comprehensive knowledge of the following elements which influence their applicability and effectiveness:

1. Advantages and disadvantages of liquid and grease lubricants.

2. Types of liquid and grease lubricants available, and their physical, chemical and performance characteristics.

3. Design parameters such as the operating conditions, and space and weight limitations affecting the unit or part to be lubricated.

4. Type of unit or part to be lubricated - as gears, bearings, slides, screws et cetera.

5. Factors influencing lubricant performance as:

a. Mechanical - speed, load, et cetera.

b. Environmental - temperature, vacuum, radiation, et cetera.

6. Methods by which grease or liquid lubricants can be applied and the relative merits of each method.

7. Types of devices available for applying the above methods of lubrication and the influence of varying the mode of installation.

Since each one of the contributing elements listed covers a wide field of knowledge, this paper will only be able to touch briefly upon some of these topics due to space and time limitations, however, references where additional information can be obtained are given at the end of this paper.

A. ADVANTAGES AND DISADVANTAGES OF LIQUID AND GREASE LUBRICANTS

Some or all of the following important advantages offered by liquid lubrication are; it allows hydrodynamic lubrication, provides minimum friction and power loss, high speed operation of ball bearings up to 2 X 10^6DN is possible, gives positional accuracy for lengthy periods of time, gives long operating life and reliability, permits wide temperature operation, high temperature operation is feasible for long periods, insures minimum vibration from moving elements, long storage life, resists shock and vibration, the liquid feeds readily into loaded contact areas, satisfies lubrication requirements of equipment containing more than one element such as gears, bearings, and other sliding surfaces, serves as heat transfer medium, removes debris and other contaminants from contact areas, low torque starting and running requirements of precision instruments and guidance control equipment can be met, permits extremely close tolerances between moving parts and can be used for power transmission mediums.

Some of the possible disadvantages encountered with oil lubrication are; necessity of complex housing designs, seals, feeding devices, increased weight, size, and power needs of the lubrication systems, leakage and evaporation problems, and increased maintenance problems over greases and solid lubricants.

Grease lubrication has become more and more the favorite method of lubricating in aerospace equipment because of its inherent advantages and the fact that these advantages coincide with the need for minimizing the weight and space of equipment used in aircraft, missiles and spacecraft. Greases act as an effective barrier and sealant against dirt and moisture preventing the leakage normally encountered with liquids. Machine design is simplified since the need for complex lubricant systems is eliminated, thereby many weight and space problems are relieved. A greater range of additives can be used in greases and in much larger amounts than with liquids giving better load carrying ability, rust protection, et cetera. Seals are easier to design and are not as likely to cause increased friction and power consumption as in the case of liquid lubrication. Maintenance is either eliminated or greatly minimized. Elements such as ball and roller bearings can be pre-packed providing life time lubrication on installation and insuring correct selection of lubricant.

They make excellent gear lubricants because of the ability to provide thixotropic materials preventing complete drainage of lubricant from exposed gear teeth during inoperative periods minimizing starting friction, and because they cushion gear teeth against shock and vibration damage. High temperature lubrication for ball and roller bearings, and gears can be provided equal to that of liquid lubricants but with a lower overall performance life. High speed performance in ball bearings can be obtained up to $.6 \times 10^6$ DN for several hundred hours. Provides lubrication in media such as fuels, water, and acids.

There are disadvantages to grease lubrication, for example; greases cannot remove debri and degradation products from contact areas. There usually is only a limited amount of lubricant available, i.e., that within the immediate cavities of the bearing or gear housing and there it is continually exposed to operational and environmental conditions. It cannot be purified like liquid lubricants in circulatory systems. Higher starting and running torques and slight but ever changing consistency characteristics make it second to liquid lubrication in low powered instruments and guidance equipment.

There are a limited number of methods of grease application and few devices to accomplish it. Shelf storage life of greases in containers and in prepacked bearings is usually limited to less than five years. They cannot act in a heat transfer capacity comparable to liquid lubricants. It does not feed as readily into loaded contact areas as do liquid lubricants. Operational life at high speeds and high temperatures is shorter than with liquid lubricants.

High speed capacity is much lower than that of liquid lubricants. Requirements of various different type elements within aerospace equipment sometimes cannot be satisfied by one or any grease lubricant as is usually possible with liquid lubrication.

B. CURRENTLY AVAILABLE LIQUID AND GREASE LUBRICANTS

The various types of equipment and the various elements contained in them that will require lubrication in aerospace vehicles and their supporting equipment are given in Table 1.

The lubricating liquids and greases to be discussed in this paper are divided into specific classes by the types of base oils used in their formulation. Each specific class of lubricant will be given in a table listing all its potential greases and liquid lubricants, their temperature range and general applications. The applications include equipment types and the kinds of sliding and rolling elements they may contain. They are indicated by the alphabetical code used in Table 1.

The liquid and grease lubricants contained in Tables 2 and 5 are the materials most commonly used or, in the case of experimental materials, those which show the most promise. The applications are general ones, and there are always many exceptions due to specific operating conditions and/or environmental surroundings.

C. LUBRICATION METHODS

The choice of lubrication methods should be carefully considered and should be based on the need of the specific application. The following factors are to be considered:

1. What is the correct flow rate?

2. What method will supply it?

3. If the rate varies can the chosen method adapt to meet the changes?

4. Is the flow rate independent of reserve supply of lubricant?

5. Reliability of the method? Can it perform under less than ideal conditions?

Methods for lubrication fall into the following:

1. Manual

2. Drop feed

3. Splash or Bath

4. Ring, chain or collar

5. Pad and wick type

6. Positive face feed

7. Air-oil mist

8. Circulating Systems

9. Centralized Systems

10. Built-in lubrication

There are numerous devices for providing lubricants by any of the above methods and everyday there are new ones appearing that offer some specific advantage over those being used in a certain application.

The constant review of technical literature is necessary to keep abreast of the state-of-the-art in this field.

D. FACTORS INFLUENCING LUBRICANT PERFORMANCE

Performance of liquid or grease lubricants are greatly dependent upon operational and environmental factors.

Important operational factors include; speeds, available torque, loads, size of bearings, gears and other elements, design of bearing, gears and other elements, seals, shock, vibration, operating cycles, motion, metal combinations and other special conditions.

Critical environmental factors are: temperature, high pressure, contaminants, vacuum, radiation, oxidizing atmospheres, and inert atmospheres.

E. LUBRICATION PROBLEMS AND SOLUTIONS

The following is a typical example of what happens when a choice of lubricant and lubrication method is made without the knowledge outlined in the proceding portion of this paper on conventional lubricants. An industrial firm develops a revolutionary design for a large secondary power component for use in a military aircraft. If this unit proves successful the manufacturer hopes to introduce it into commercial jet aircraft where because of its compact design and power source it will undoubtedly be widely accepted. Briefly the unit requires lubrication of a large vertical gear train and 20 mm ball bearings at speeds of 28,000 rpm, moderate to heavy loads, and temperatures of 275°F to 300°F for 500 hours. The manufacturer chooses a thixotropic grease lubricant for both the lubrication of gears and ball bearings. Unfortunately at that time grease lubricants are not capable of providing reliable, long term operation under these conditions in ball bearings. The result is a series of catistrophic failures of the new unit resulting in at least one instance of the loss of an aircraft. Subsequent review by both service and industrial bearing and lubrication personnel produces recommendations that oil lubrication be used with a forced feed circulating lubrication system and that the size of the 20 mm bearings be increased to 30 mm. These changes are made by the manufacturer. The redesigned unit requires very little change in its overall size and provides satisfactory operation for 500 hours with good reliability. However, the redesign and modification requires nearly a year and during this time the military aircraft is converted back to the conventional type secondary power unit used previously. As a result even though the redesigned unit has now proved its feasibility and reliability it will not be used in this aircraft. Due to adverse publicity obtained by the grease lubricated unit the manufacturer never is able to market it commercially. The obvious result is that a basically good design with a potential market is lost because of a faulty choice of lubricant and lubrication method even though the correct lubricant and method of lubrication were readily available with a long history of successful operation under similar conditions.

In another possible example, a request is received for a grease lubricant for a ball bearing application operating at 600°F, moderate speed, and heavy loads, but more specific information cannot be obtained. A grease with an extreme pressure agent is recommended on the basis of its successful performance under similar conditions. Shortly afterward, word is received that the grease has failed. During the discussion of the lubricant failure it is disclosed that the failure is due to corrosion of titanium metal located somewhere in the component requiring lubrication. Immediately upon receipt of this information it is a simple matter based on past experience with titanium metals and lubricants to correct the problem. It is merely a matter of removing the extreme pressure agent from the grease and substituting another compatible load carrying agent. Once this is done, satisfactory lubrication was achieved with the grease and corrosion was eliminated.

Finally, a problem concerns the lubrication of small gears at 60,000 rpm at temperatures of 1,000°F under light loads. This unit is to operate in an application where size and weight of the component and its lubricating system must be held to a minimum. The operational life of the unit is probably, dependent upon its mission, no greater than 25 hours. Since it will be used in a defensive system the lubricant must have storage stability preferably of 5 years at least. A review of current lubricants reveals that there are no liquid or grease lubricants capable of withstanding 1,000°F temperatures. There are solid film lubricants capable of 1,000°F operation, however, they give poor performance below 700°F. Solid lubricants capable of low temperature operation are good only to +550°F.

A suggested approach from the lubrication engineers view point would be to use a combination of liquid and solid lubricants. A liquid lubricant is known which will lubricate up to +700°F without forming harmful deposits. Space limitations preclude the use of a circulating oil system, therefore either an oil bath or oil wick system using this lubricant might be used with the high temperature solid film coating applied to the gears. The idea here being the oil would lubricate at temperatures below 700°F and above 700°F the solid film would take over. By keeping the oil in a bath or wick system the rate of oil volatility could also be controlled.

The solution to these types of problems calls for close cooperation between the designers, manufacturers and lubrication engineers. Possible approaches must be thoroughly discussed from each others view points. Mock-up systems should be built and studied, incorporating those approaches which appear feasible. Necessary changes in lubricant characteristics and design dictated by these tests should be made and their merit determined.

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Table 1 — Equipment Types Requiring Lubrication In Aerospace Vehicles And Supporting Equipment

	Type of Equipment	Type of Sliding and Rolling Elements
A	Electric Motors, Generators, Alternators, Electronic Equipment	Ball, Roller and Plain Bearings
B	Invertors, Actuators	Gears, Screw Mechanisms, Ball and Roller Bearings
C	Gear Boxes, Speed Reducers	Gears, Sliding Surfaces, Ball Roller and Plain Bearings
D	Guidance and Control Mechanism, Camera, Radio & Radar Equipment	Ball, Roller and Plain Bearings, Pulleys and Sliding Surfaces
E	Gas Turbine Engines, Compressors, and Engine Hydraulic Systems	Ball, Roller and Plain Bearings, Gears, Pumps, Fuel Regulators, Rotating Seals, Valves, Servo Mechanisms
F	Hydraulic Systems for Secondary Power and Guidance and Control Mechanisms, Gantry Towers, Ground Equipment	Ball, Roller, and Plain Bearings, Pumps, Valves, Servo Mechanisms
G	Gyros, Instruments	Ball and Plain Bearings, Sliding Mechanisms, Gears
H	Wheels, Landing Gear	Ball, Roller and Plain Bearings, Sliding Mechanisms

Table 2 - Mineral Oil and Synthetic Hydrocarbon **Liquids and Greases**

	Specification, Nomenclature and Temperature Range	General Applications							
		A	B	C	D	E	F	G	H
1	MIL-H-5606, Hydraulic Fluid (-65° F to +275° F)						X		
2	MIL-H-27601, Hydraulic Fluid (-40° F to +550° F)						X		
3	MIL-C-6081 (B) Gas Turbine Engine Oil Grade 1005 (-65° F to +150° F) Grade 1010 (-40° F to +175° F)					X			
4	MIL-L-6086 (B) Gear Oil (-40° F to +160° F)			X-	X				
5	MIL-L-7870 (A) General Purpose Oil (-65° F to +250° F)	X			X			X	
6	MIL-G-7711, General Purpose Grease (-40° F to +250° F)	X			X			X	
7	MIL-G-3545, Ball and Roller Bearing Grease (0° F to +300° F)	X			X				X

Table 3 - Lubricating Oils and Greases Derived From Aliphatic Esters

	Specification, Nomenclature and Temperature Range	General Applications							
		A	B	C	D	E	F	G	H
1	MIL-L-6085, Instrument Oil (-65° F to +250° F)				X			X	
2	MIL-L-7808, Gas Turbine Engine Oil (-65° F to +300° F)	X		X		X			
3	MIL-L-9236, Gas Turbine Engine Oil (-65° F to +425° F)					X			
4	MIL-G-23827, General Purpose Grease (-65° F to +250° F)	X	X	X	X			X	
5	MIL-G-7421, Extreme Low Temperature Grease (-100° F to +225° F)	X			X			X	
6	MIL-G-21164, Heavy Load Carrying Grease (-65° F to +250° F)	X	X	X	X				
7	MIL-G-25760, Wheel Bearing Grease (-65° F to +350° F)	X			X				X

Table 4 - Lubricating Oils and Greases Derived From Silicon Liquids

	Specification, Nomenclature and Temperature Range	General Applications							
		A	B	C	D	E	F	G	H
1	MIL-H-8446, Hydraulic Fluid (-65° F to +400° F)						X		
2	MIL-L-27694, Instrument Oil (-65° F to +400° F)				X			X	
3	Chlorinated Phenyl, Methyl Silicone Oil (-65° F to +450° F) General Electric F-50, Dow Corning F-60	X			X	X			
4	MIL-G-25013 (D), High Temperature Grease (-100° F to +450° F)	X			X			X	X
5	MIL-G-27343, Wide Temperature Grease (-100° F to +450° F)	X			X			X	
6	MIL-G-27549, Heavy Load Carrying Grease (-65° F to +425° F)	X	X	X	X				X
7	MIL-G-27617, Fuel and Oil Resistant, Shock Resistant Liquid Oxygen * (-30° F to +400° F)			X		X	X		
8	MIL-G-38220, High Speed Ball Bearing (-40° F to +400° F)	X		X	X				
9	Lithium Soap - Chlorinated Silicone Grease (-65° F to +300° F) Example - Versilube 300	X			X				

* Not derived from silicone liquid.

Table 5 - Experimental Liquids and Greases

	Nomenclature, Temperature Ranges	General Applications							
		A	B	C	D	E	F	G	H
1	Fluorinated Silicones (-80° F to +450° F) in various temperature ranges			X		X	X		
2	Polyphenyl Ethers (0° F to +700° F) in various temperature ranges	X		X		X	X		
3	Cyclic Phosphonitrilates (-20° F to +700° F) in various temperature ranges			X					
4	Pyrazines (-65° F to 700° F) in various temperature ranges					X	X		
5	Ammeline-Silicone Grease, High Speed Ball Bearings, DN 600,000, Temp 400° F Light Loads	X		X	X	X	X		
6	Teflon-Fluorinated Silicone Grease, Heavy Load Carrying (-30° F to +400° F)	X	X	X	X	X	X		
7	Carbon Black - Silicone Grease (-65° F to +550° F)				X				